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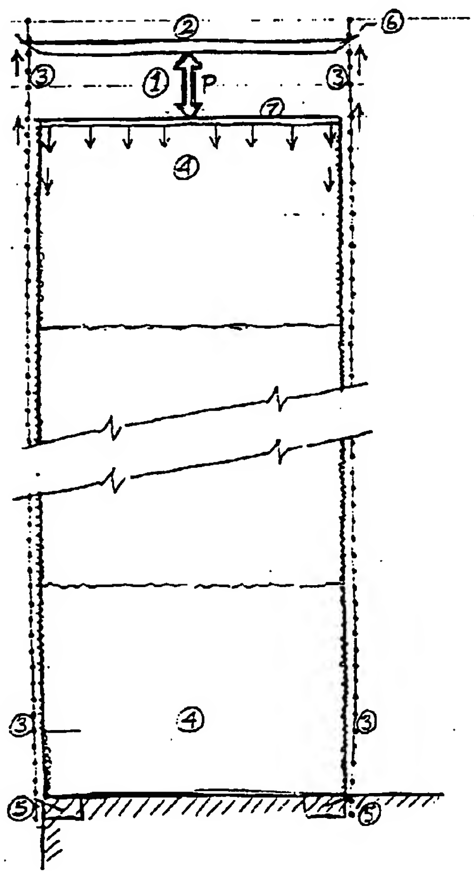
(54) **PRECONTRAINTE ET ARASEMENT DE MURS EN BALLES DE FOIN OU EN BLOCS DANS LES PROCEDES DE CONSTRUCTION UTILISANT LA TECHNIQUE MECANO**

(54) **PRESTRESSING AND LEVELLING STACKED BALE OR BLOCK BUILDING CONSTRUCTIONS**



(57) La précontrainte de balles de foin empilées ou de blocs utilisés dans la technique de construction mécano est effectuée à l'aide d'un réseau maillé recouvrant les deux faces opposées de la structure; ce réseau maillé est généralement incorporé afin de contribuer au renforcement du mortier pour enduit à base de stuc ou de gypse utilisé dans les revêtements aux fins de protection contre les fissures attribuables au retrait. Dans l'érection du mur, le réseau maillé situé de part et d'autre de la

(57) Prestressing stacked bale or block building constructions is effected by means of mesh which covers the two opposing faces, which mesh is normally incorporated to reinforce the final stucco/gypsum renderings or the like against shrinkage cracking. In a wall structure, the mesh on each face is grasped simultaneously at the top and pulled upwards while pushing down upon the top of the stacked bales; thus the tensioning of the mesh simultaneously and equally

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structure est saisi par sa partie supérieure et tiré vers le haut pendant qu'une pression est exercée vers le bas sur les éléments empilés. Cette compression a pour effet d'accroître résistance du mur au cisaillement et, combinée au tensionnement du réseau maillé, améliore la cohésion de la structure composite du bâtiment, ce qui contribue à l'obtention des conditions nécessaires pour la réalisation de revêtements muraux de qualité satisfaisante pour prévenir efficacement les risques de fissures attribuables au retrait ou autres forces de traction. La méthode produit un surplus de réseau maillé au sommet du mur ainsi comprimé, surplus qui constitue une façon idéale d'ancrer le toit à la fondation. L'opération de précontrainte peut être effectuée par des moyens pneumatiques, hydrauliques ou mécaniques; un système faisant appel à des tubes pneumatiques est proposé. La méthode proposée permet aussi l'arasement final de la face supérieure des murs. Un système de soutènement par corde tendue est également dévoilé. La méthode et le matériel peuvent aussi être utilisés dans les systèmes de soutènement de toit, notamment pour le soutènement de toits de forme incurvée.

compresses the bales or blocks vertically. That compression increases the wall's shear resistance, and together with the tensioning of the mesh produces an adequate composite building structure, obviating most or all dependency on the tensile qualities of any final renderings or coverings, and effectively preventing shrinkage cracking or other tensile cracking of same. The method results in an excess of mesh atop the compressed wall, which mesh can be secured to the roof structure to effect ideal tie-down to the foundation. The prestressing may be effected pneumatically, hydraulically, or mechanically; a preferred pneumatic tube device is disclosed. The method also accomplishes the final levelling of the walls. A "tightrope form" construction support system is disclosed. The method and apparatus can be used as well to produce roof structure particularly in arched form.

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PRESTRESSING AND LEVELLING STACKED BALE OR BLOCK BUILDING CONSTRUCTIONS USING SURFACE MOUNTED MESH

- **Robert Platts and Linda Chapman** -

ABSTRACT

Prestressing stacked bale or block building constructions is effected by means of mesh which covers the two opposing faces, which mesh is normally incorporated to reinforce the final stucco/gypsum renderings or the like against shrinkage cracking. In a wall structure, the mesh on each face is grasped simultaneously at the top and pulled upwards while pushing down upon the top of the stacked bales; thus the tensioning of the mesh simultaneously and equally compresses the bales or blocks vertically. That compression increases the wall's shear resistance, and together with the tensioning of the mesh produces an adequate composite building structure, obviating most or all dependency on the tensile qualities of any final renderings or coverings, and effectively preventing shrinkage cracking or other tensile cracking of same. The method results in an excess of mesh atop the compressed wall, which mesh can be secured to the roof structure to effect ideal tie-down to the foundation. The prestressing may be effected pneumatically, hydraulically, or mechanically; a preferred pneumatic tube device is disclosed. The method also accomplishes the final levelling of the walls. A "tightrope form" construction support system is disclosed. The method and apparatus can be used as well to produce roof structure particularly in arched form.

6 claims, 3 drawings

BACKGROUND OF THE INVENTION

The provision of affordable housing is increasingly limited by the supply of basic resources. Material resources are becoming less plentiful and less accessible, and material extraction is becoming more costly, energy consuming and polluting. Building production as well as material production becomes more capital intensive and costly in the very efforts to produce more from less.

Even wood frame construction, clearly the most successful system based on renewable fibre, is consuming its forest resources at a questionably sustainable rate. The forest product innovators have been responding for decades, to assure sustainability and "value-added" profitability, by getting much more house from each tree and indeed from what were "weed trees". The innovators all have in common the production of "reconstituted" wood fibre composite components, yielding more from less, but all at a price in energy, money and pollution terms.

More than one hundred years ago, needing good houses quickly and lacking access to lumber, Nebraska pioneers conceived an alternative form of housing from an alternative cellulose fibre, a "waste" fibre in abundant supply and needing no refinement. Handsome examples of "Nebraska Straw bale" houses are still in use from those first days. The pioneers stacked bales of straw, then let them settle, rendered them on the outside with sand-lime stucco and on the inside with that or gypsum plaster, to form load bearing exterior walls as well as gable walls and spine walls. Their followers still do.

The thermal performance of such strawbale houses would have been welcomed the first and every winter; their permanence has become clear through the twentieth century. Ample fire resistance has been demonstrated in lab and field, and sound transmission resistance is legendary. An alternative to wood frame construction, and a complementary supply of cellulose fibre, has been demonstrated.

But only to a point: the Nebraska Strawbale system, for all its simplicity and ability to utilize the "wastes" of cereal grain agriculture — which is almost as broad as mankind — is not ready to produce housing affordably in volume, "by the millions, for the millions". The failings that have marred Nebraska Strawbale construction and all such prior art are any or all of the following:

- Much of the construction process is slow and marred by redundancies and wastes. Attempts to improve stability and safety during construction include the use of hundreds of saplings — or steel rebars, in some of today's versions — as vertical dowels pinning bale to bale. They do not work well: the wall remains shaky until wrapped by the wire mesh (that receives and reinforces the stucco or plaster on both surfaces); tedious bracing and repetitious adjustments to vertical plane are entailed; and after the "skins" cure, all those saplings or rebars have nothing whatever to do.

- Before the skins are applied, a settling period of 4-8 weeks is deemed necessary, with roof in place, to compress the bales sufficiently for the stucco/plaster work to commence on a stable base. The long settling period interferes with construction flow and leaves the straw exposed to wind-driven rains unless well tarpaulined. (Building with dry fibre, and keeping it dry, is critical to ensure rot-free durability.)

- The shaky, uneven wall can take great amounts of stucco/plaster to form plane surfaces; it may not accept the impact of modern "shotcreting"; the hand-stuccoing is very laborious.

- The final structural properties rely very largely, if indeterminately, on the strength and stiffness of the skins, and next on the straw's ability to transfer shear forces and to stabilize the skins against buckling under load. Straw bale construction is in fact a stressed skin "structural sandwich" construction largely dependent upon the presence of cementitious or like skins and particularly limited in structural performance by the skin's tensile properties and the straw bale's transverse shear and tensile properties.

- The cementious renderings are prone to shrinkage cracking and other cracking, which can allow the ingress of moisture which promotes rotting of the straw.

- Nebraska strawbale construction and its derivatives can readily produce only the exterior walls, which constitute just a small fraction of a building. Limitations in strawbale shear and skin tensile properties make it generally unsuitable for forming the roof-ceiling, to complete the essential building envelope.

In the prior art, methods of precompressing the bales have been suggested, with the stated goal of eliminating the settling period. One approach utilizes threaded steel rods rammed vertically through the middle of the bales, drawing down a top plate by turning down nuts

on these wall-height rods. That strengthens the wall only slightly, in that the rods are close to the neutral axis of the wall. Another recent method employs straps or wires cast over the top plate and tightened to draw the bales down; that can add significant bending strength to the wall. Such approaches require extra materials and steps and fail to prestress the skins or reinforce them against tensile cracking and admittance of moisture.

SUMMARY OF THE INVENTION

The present invention is firstly designed and test-proven to overcome or greatly ameliorate the drawbacks of the Nebraska Straw Bale wall construction, and to do so with less components in the structure, not more. It presents similar advantages with stacked baled fibre constructions using other fibres, and it offers certain advantages in prestressing walls of rigid block construction as well. It is a method of using a reinforcing means positioned over the two faces of a bale or block wall to compress said wall vertically, simultaneously tensioning the means vertically with equal force. This prestressing readies the stacked bales to accept vertical loading without further deformation, greatly increases the shear of the strawbales to help develop both bending and racking resistance, and reduces or eliminates structural reliance on skins or coverings, particularly in tension, so that neither skin quality nor skin cracking (and admittance of moisture) need any longer be of great concern. A "tightrope form" method of construction support is disclosed which eliminates any need for dowelling the stacked bales or other onerous attention to construction bracing. The ready-to-prestress assembly is secure and amenable to one-step adjustments to plane; the quickly prestressed composite is readily "fine levelled" using the prestressing means; and the composite is already strong enough to accept the weight of floor and roof structure and the impact of "shotcreting" or like applications. The composite can be prestressed adequately to form roof-ceiling structures including arched roofs.

In accordance with the invention, reinforcing means, anchored to the base of a construction of stacked bales or blocks, is stretched over each face of the construction by means and in a manner that simultaneously applies pressure to compress the construction.

The blocks may be of baled fibre form, the term "straw bale" or "bale" herein connoting any baled or otherwise compacted, bound, jacketed or covered block of any fibre, e.g., cereal straw, hay, bagasse, thatch palm, shredded wood or mixtures of such; or the blocks may be rigid building blocks. e.g., concrete block of high or low density.

The reinforcing means may be strong mesh or fabric, or closely spaced wires, cords, or ribbons; the mesh or fabric is broadly preferable in that it can more readily do double duty as pre-tensioned reinforcing for cementitious or like "skins" of the stucco family, say, or as a taut sheathing upon which various claddings may be mounted, in addition to its duty of compressing the stacked bales or blocks.

The means to apply force may be pneumatic, hydraulic or mechanical in nature, in the form of pressure tubes or a series of jacks such as automobile jacks, or levers or the like, preferably positioned atop the stacked bales or blocks so that the reinforcing means over both faces can be tensioned upward in one operation. The force may be applied downward against a permanent top plate atop the bales or blocks and at the same time upward against a temporary frame or plate that grasps the reinforcing means and lifts and tensions it accordingly. Alternatively, the reinforcing means may be a strongly shrinkable mesh or fabric such as heat-shrinkable material which itself may be caused to produce the prestressing tension and compression force.

The means to apply force may be used to level the wall top once the desired degree of prestressing and compaction has been achieved, adjusting the wall height to the desired elevation.

The reinforcing means may then be secured to the wall top by nails, staples, battens or such to form the prestressed and levelled structure ready to accept structural skins or simply non-structural claddings as the designer chooses to meet the expected service conditions.

Structural skins can be applied in the form of cementitious or gypsum or clay or like "wet applied" renderings, by hand or preferably by "shotcrete" or like mechanical means; such wet applications penetrate into and bond very effectively to the outermost fibres of the stacked bales, so that the transverse-oriented fibres support and stabilize the skins against buckling under load, thus assuring adequate structural sandwich or stressed skin composite action.

Where the designer chooses further assurance of structural composite performance, for example where the wall is unusually high or spans and snow loads are great or seismic activity is anticipated, cross-tie wires or cords may be threaded transversely through the bales wherever desired and secured to the mesh or other reinforcing means on each face, thus further stabilizing the skins against buckling under load.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings illustrate preferred embodiments of the present invention and, together with the description, serve to explain its principles; the drawings are not to be construed as limiting the invention. In the drawings:

Fig. 1 is a schematic section of a stacked bale or block wall, showing the use of face-mounted reinforcing means and top-mounted prestressing means according to the preferred embodiment of the invention;

Fig. 2 is a perspective view of the top area of said wall, showing the reinforcing means in mesh form and the prestressing means as a pneumatically or hydraulically pressurized tube, and also showing a rope or cable positioned to serve as a "tightrope form", all according to the preferred embodiment of the invention; and

Fig. 3 is a section of a portion of a bale assembly showing an assymetrically positioned prestresser forcing the assembly to curve suitably to form the core of an arched roof composite structure, as one manner of constructing a prestressed roof-ceiling structure according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the drawings, like numerals indicate like elements on each of the views. While a wall structure is usually illustrated and described herein, and is the original subject needing improvement and addressed by the inventors, roof and floor structures are also encompassed within the invention and similar methods and apparatus apply.

Reference is made first to **Figure 1** in which the prestressing method is illustrated schematically, then to **Figure 2** which represents the preferred embodiment more graphically. Straw bales **4** are stacked on a base **5** to a desired height which allows for their intended compression. A strong mesh such as "chicken wire" is nailed or otherwise anchored to the base **5**, then passed up the wall and secured to the top-mounted prestresser apparatus **2** by means of fingers **6**. The positioned mesh is then clipped together along its vertical edges, e.g. with "hog rings" or short wire ties, so that it can as one mesh plane and tensioning of the mesh can be applied uniformly. The application **1** of a force **P** pushes a plate **2** upward, tensioning the mesh **3** on each side of the stacked straw bales **4**, while simultaneously and equally pushing the bales **4** down, compressing them together and internally. In the

alternative, the mesh is simply passed up and over a plain plate or frame such as an aluminum ladder and continuously down to anchorage to the floor or foundation on the other side, so that the application **1** of the force **P** pushes up the plate and thereby the mesh, accomplishing the prestressing without the need of the multiple fingers shown in the figures. (This embodiment entails considerable savings in equipment costs but that must be weighed against a slightly excessive use of mesh.)

The designer can calculate the force **P** to achieve structural benefits to the desired degree; for example, **P** can so exceed the loads that the stacked bales will encounter in service, and more so to allow for eventual creep or stress relaxation, that the mesh **3** will never lose its tension even under maximum load; hence any skins or coverings will never have to resist tension in themselves and skin quality becomes of little structural consequence. Indeed, no structural skins need be added to form an adequate wall structure for low-rise buildings facing common load conditions; non-structural prefabricated claddings may be hung or secured on appropriately prestressed mesh to form attractive finishes with desired barrier qualities against the transfer of air, water vapour, rain, fire, sound and other undesired intruders into or through the wall. Finally, the force **P** can be varied further to level the wall top at the desired uniform elevation. Then the mesh **3** is secured to the edge areas of the top plate **7**, by stapling or nailing for example. The structure is complete, ready for further floors or roof and final rendering or covering of the surface. The apparatus **1**, **2** is now removed. The excess mesh left protruding above the top plate **7** can be used to tie down the roof structure; the tie down is directly to the foundation and the prestressed structure can indeed be made uniquely resistant to severe windstorm loads as well as seismic loads.

In **Figure 2**, the preferred apparatus is shown applying the prestressing force **P** by means of a pneumatic pressure tube **1**, inflated by means of an air compressor or large diameter hand pump. Such a bladder may also be used hydraulically, with pumped water or other fluid; or the plate **2** can be designed to afford access to operate scissor jacks or hydraulic jacks as commonly available, or even long levers; the prestressing can be accomplished with resources available practically anywhere.

The precompressing of the bales **4** increases the shear resistance within and between the bales, as well as the compression and tensile moduli involved in stabilizing final skins of the structural sanwich or stressed skin composite, while the pre-tensioning of the mesh **3** completes the composite structure as described to achieve substantial strength and resilience without calling upon tensile qualities of the final skin coverings. The accompanying chart

"Load/Deflection Curves - Stuccoed Strawbale Wall Sections" shows the tested bending resistances of wheat straw bale walls 8 feet high, 18 inches through, with 3/4 inch stucco skins reinforced with "chicken wire" mesh in the usual Nebraska manner and the prestressed manner of this invention. Indeed, the tests suggest that the designer can prestress to a degree where the composite structure as described can form roof assemblies. **Figure 3** depicts an option wherein a curved composite can be formed by simply biasing the application of the force **P**, **1**; arched roofs can be formed so, affording considerable spans while reducing shear and tensile demands by virtue of the arched form. Wire ties **8** (**Figure 3**) are required with such bowed composites to force the inner mesh to remain aligned with the curve.

Again considering walls, the designer may use such wire ties **8**, **Figure 3,** in further ensuring the stability of the skins against buckling under compressive loading in various conditions including: where the wall is unusually high; where seismic loads or other severe conditions are indicated; and/or with packaged or covered bales where the fibre is not exposed to key into the applied stucco or the like and so cannot act by itself to stabilize the skins against buckling.

The mesh application and prestressing operations are ideally suited to achieving construction stability and safety as well as vertical planarity without requiring dowels or other permanent adjuncts. In **Figure 2**, a taut cable or rope **9** is shown positioned to serve as a "tightrope form" for construction support. It may be strung just above head height, to which height the stacked bales are reasonably stable without support. The cable, strung between temporary corner posts for example, and tightened, guyed or stayed as required, provides a guide for precise vertical stacking and then stabilizes the wall by means of grapples or wire ties through the bales. The mesh **3** is readily passed up over the cable and secured as described above; the wall is now remarkably stable, as full trials have shown, ready for prestressing, while the bales can be pushed into final vertical alignment if necessary, and will stay in place awaiting and during the prestressing. The cable or rope can be easily removed before final shotcreting or other rendering or cladding operations are begun.

We claim:

1. A method of using reinforcing means such as strong mesh covering both faces of stacked bale or block wall constructions to prestress the constructions, tensioning the mesh while compressing the bales or blocks, comprising the steps of:

a) grasping and pulling vertically the reinforcing means which covers the surfaces of the stacked bales or blocks, and which has been anchored at their base, thereby tensioning the means while simultaneously pushing down the bales or blocks and compressing them internally and together;

b) then fixing the pretensioned means to a top plate positioned over the compressed bales or blocks to create a prestressed composite wall structurally adequate in itself and so not relying much or at all, as the designer chooses, on a final rendering to impart structural qualities and particularly tensile qualities.

2. A method according to claim 1, whereby the prestressing force is applied atop the stacked bale or block wall in a manner that at once tensions the mesh on both faces of the assembly and simultaneously compresses the bales or blocks together and internally, by means of a pneumatically or hydraulically pressurized tube or a sufficient number of jacks, levers or such devices mounted along the top of said assembly.

3. A method according to claim 1 whereby the wall top is precisely levelled during said prestressing operation, by:

a) first effecting an over-compression by applying excessive pressure until even the highest point of the wall is forced down to the suitable final elevation;

b) fixing the reinforcing means to the top plate at that point to fix the wall height there;

c) then relaxing the pressure in small steps until each and every point along the wall has sprung back up to the desired elevation, and likewise fixing the wall height at each point and so along the whole; or

d) in the alternative, especially where jacks, levers or such devices are used to apply the prestressing/ compressing force, forcing all points of the wall top successively or together down to the desired elevation and then fixing the reinforcing means to the top plate to fix the wall height.

4. An ancillary method that works with the method and apparatus of claim 1, imparting construction stability and vertical planarity by means of one or more taut cables or ropes temporarily strung horizontally at appropriate height or heights, which cable and retainers temporarily secure the stacked bales as well as window, door and like components until the mesh is applied over the whole; and following which mesh application, final vertical aligning of bales, and prestressing and fixing of the structure, the cable can be readily pulled out from behind the mesh and final renderings or other skins can be applied.

5. A prestressed composite structural wall assembly comprising stacked bales or blocks compressed together by means of pre-tensioned reinforcing means covering both faces of the assembly, wherein the reinforcing means such as wire mesh:

   a) extends upwards to afford tie-down of the roof through to the foundation by means of fixing the top of the mesh to the roof structure and the bottom to the floor or foundation;

   b) is tensioned to a degree whereby the assembly is permanently capable of withstanding maximum expected service loadings with appropriate margins of safety, and

   c) is tensioned to a degree that obviates or appropriately reduces the need for or chances of the final renderings to be subjected to tension and thereby suffer deleterious cracking.

6. A method according to claim 1 where the degree and bias of prestressing can form composite roof or floor structures from bales or blocks by:

   a) prestressing sufficiently to impart shear resistance, creep resistance, tensile and other properties sufficient for roofs and their bending loads particularly, once rigid renderings or other structural skins have been formed, and/or

   b) biasing the prestressing or otherwise forming and prestressing the assembly to form arched roofs in which shears and tensile forces are reduced appropriately to the structural capabilities of the composite whole, including the structural skins, by virtue of the arched geometry.

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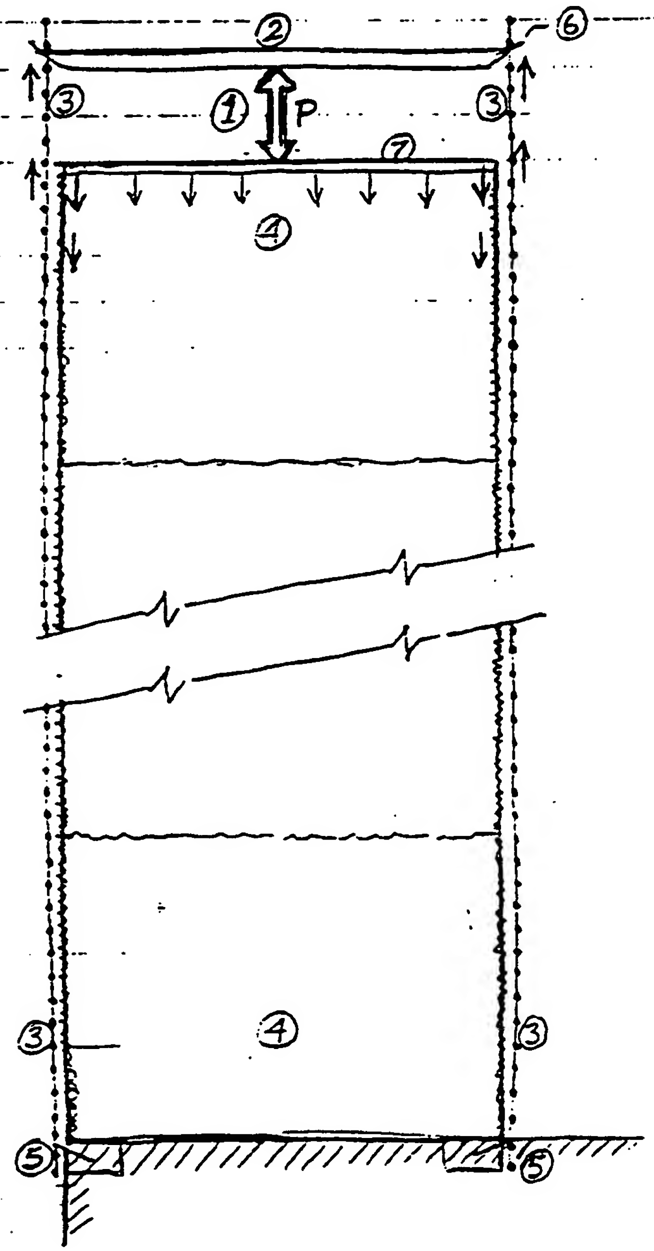

Figure 1

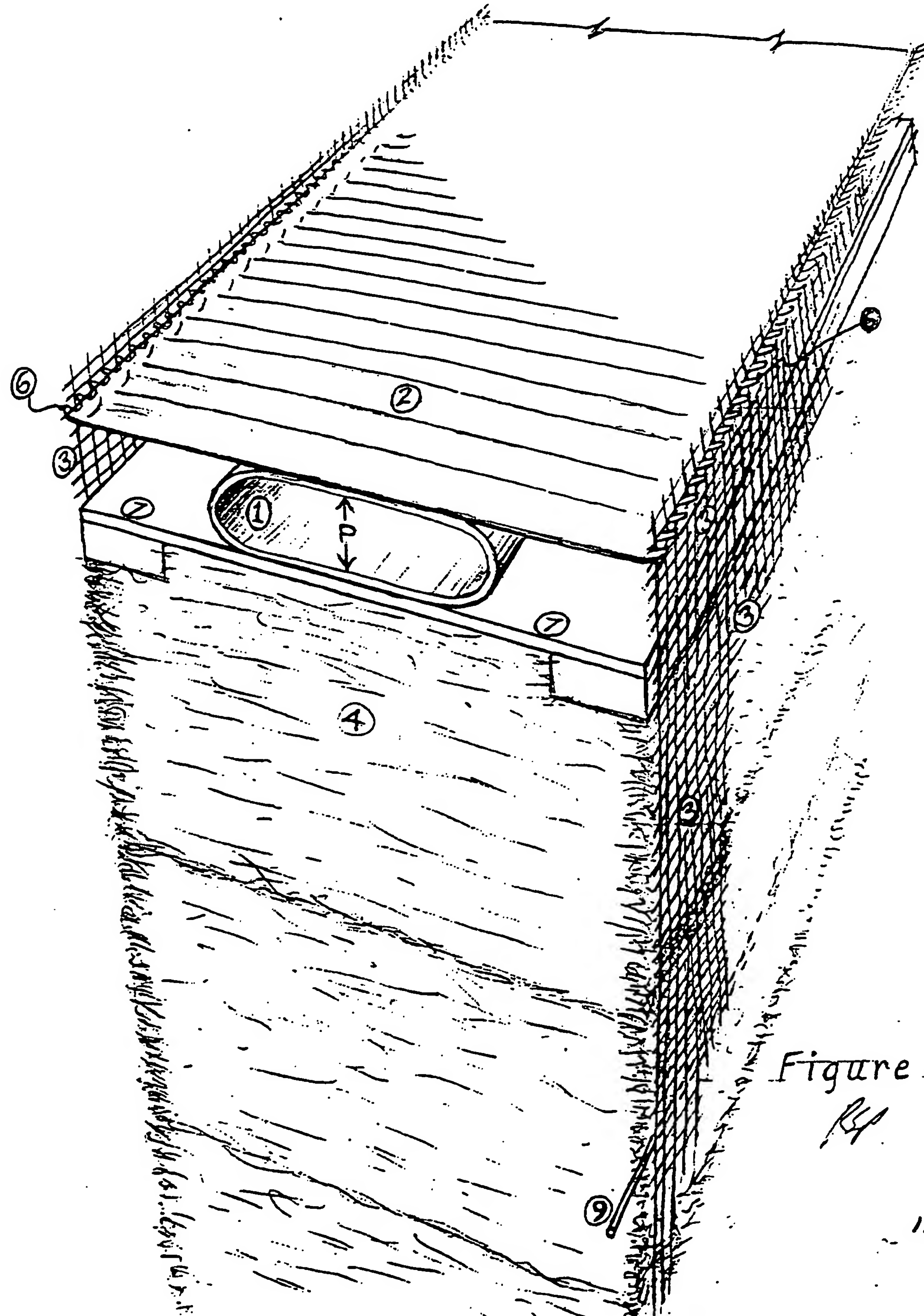

Figure 2

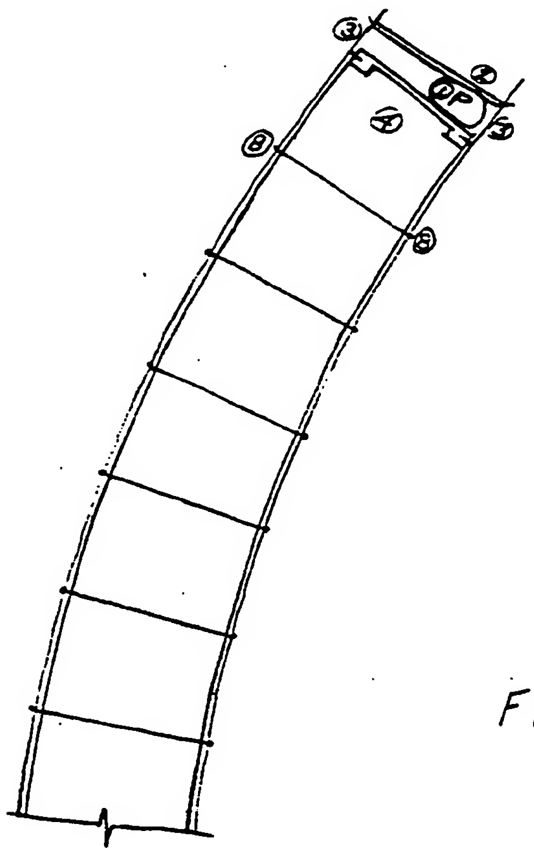

Figure 3

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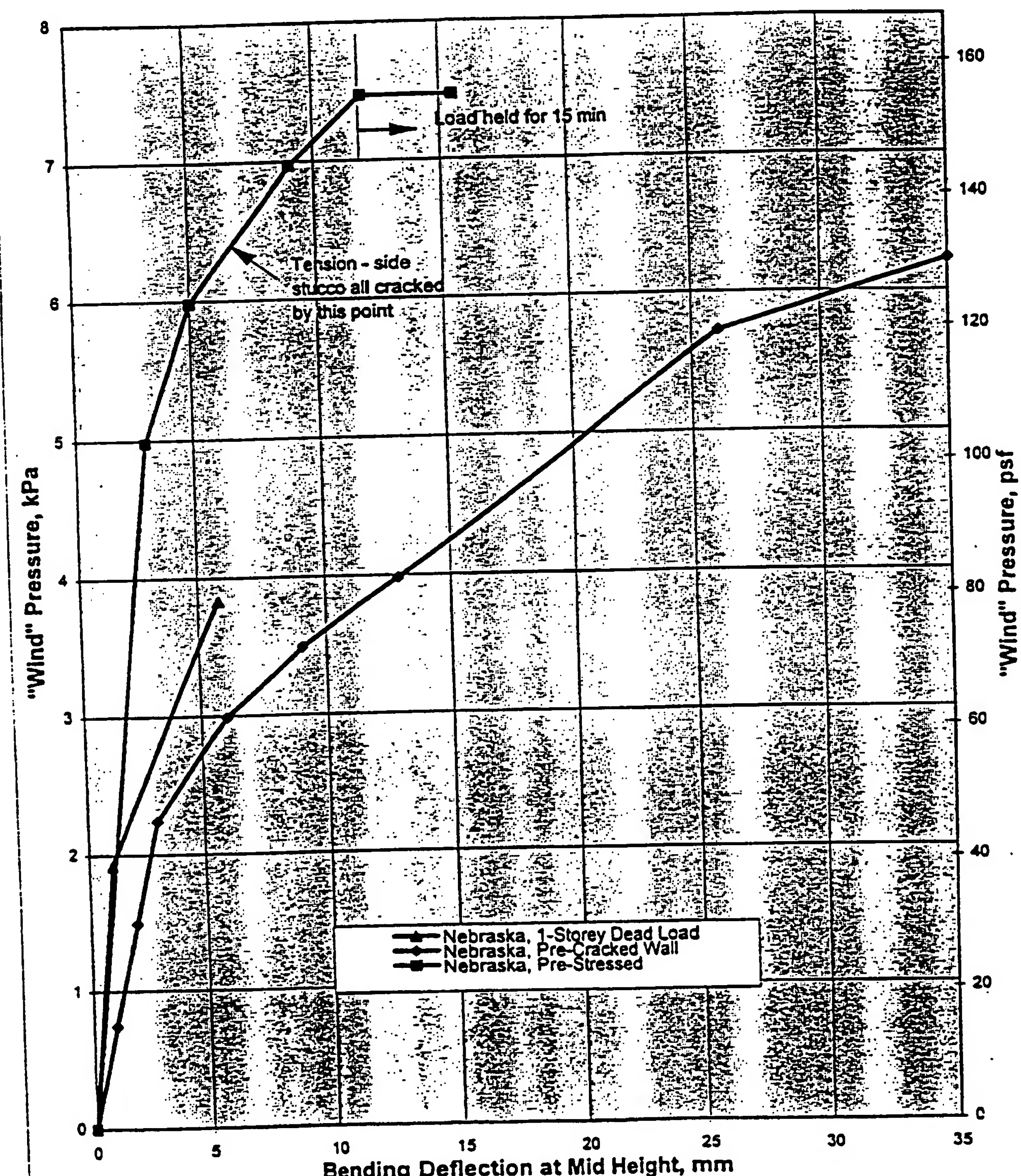
Load / Deflection Curves — Stuccoed Strawbale Wall Sections



~~Figure 3~~ Platts - Chapman Testing Rept 1996